NATIONAL BUREAU OF STANDARDS REPORT

8098

STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS

PROGRESS REPORT No. 19

April 1 - June 30, 1963

Contract No. DO (33-616)61-02
Task No. 73603

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NBS PROJECT **NBS REPORT**

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I. SUMMARY

Some progress has been made toward calibrating the wavelength drum settings with the cesium bromide prism in the wavelength range of 15 to 40 microns. The 0.484-inch diameter working standards of platinum-13% rhodium alloy and oxidized sandblasted Inconel were calibrated over the wavelength range of 1 to 15 microns, and transmitted to A.S.D.

II. INSTRUMENTATION

Air Purification System

Most of the components for the air purification system mentioned in the report for January 1 through March 31, 1963, were received during this report period, and installation was about 90% complete at the end of the period.

Filter Circuits

The filter circuits referred to in the preceding report were received and installed.

Long-Wavelength Accessories

Preliminary tests of the spectrometer with the cesium bromide prism and the Nernst glower source, indicated that scattered radiation is a problem at wavelengths beyond about 25 microns. Most of the scattering that causes trouble is believed to occur at wavelengths below 15 microns, and much of it is in the visible portion of the spectrum. A special AgCl disc filter, designed to pass the long-wavelength radiation up to 28μ and block the short-wavelength radiation below 4.5μ, a special CaF reststrahlen plate, designed to scatter the short-wavelength radiation and to specularly reflect the long-wavelength radiation from 15-40μ, and a black polyethylene film, which transmits only beyond 28μ, were ordered for use with the equipment. The manufacturer states that use of these accessories should markedly reduce interference from scattered radiation within the monochromator.

III. DATA-PROCESSING ATTACHMENT

The data-processing attachment is now performing a substantial portion of the operations it was designed to perform. The analog-to-digital converters on the wavelength drum shaft and the recording potentiometer operate satisfactorily. The pulses from the converters are correctly counted on the counters in the data-processing attachment, and the correct counts are displayed on the digital register. The counts are correctly punched on paper tape at the proper preselected wavelength-drum-dial increments. The paper tape reader correctly reads the prepunched numbers from the tape, and, when controlled by the prepunched paper tape, the data-processing attachment accumulates the emittance values at the preselected wavelength intervals for computation of total emittance by the 100-selected-ordinate method.

The remaining functional difficulty is that the attachment does not properly correct for "zero line" and "100% line" errors. The correction process was designed to comprise the following operations. (1) The pulses produced by the a-d converter on the potentiometer recorder are recorded on magnetic tape during the 100%-line and zero-line calibration runs, respectively. (2) The magnetic tape is played back synchronously with the specimen run, and the pulses previously recorded are read from the tape. (3) The pulses from the magnetic tape are amplified. (4) The amplified pulses are used, by means of a monostable multivibrator circuit and ratchet motor, to drive the 100% or zero potentiometer up or down scale as required to correct the measured emittance of the specimen, prior to its recording.

Tests have shown that the pulses are correctly recorded on the magnetic tape, and are correctly read from the tape. The ratchet motors also appear to be operating satisfactorily. The trouble appears to be due to malfunctioning of either the power amplifier or the gating in the multivibrator circuits. The work of correcting the remaining difficulties in the correction circuits is continuing.

IV. CALIBRATION OF WORKING STANDARDS

Calibration of two types of 0.484-inch diameter disc working standards was completed, and the standards were transmitted to A. S. D.

Platinum-13% Rhodium Working Standards

The platinum-13% rhodium specimens were received from the fabricator in the form of 0.035-inch sheet, cut into two strip specimens 1/4 x 8 in. in size. and five discs 0.484 inch in diameter. The original sheet of alloy from which the specimens were cut was approximately 1 1/16 x 8 in. in size. The 1/4 x 8 inch strips were cut from the two edges of the original sheet, and the discs were cut from the central portion of the remaining strip.

Each specimen was washed in hot tap water to which a commercial detergent had been added, rinsed in running hot tap water, then in distilled water, and finally in ethyl alcohol. Rubber surgical gloves were worn at all times while handling the specimens, and they were touched only at the ends or edges after cleaning. The specimens were dried in air and placed in a closed container, supported by the ends or edges only, for storage prior to annealing.

All specimens were annealed in an electric furnace with silicon carbide heating elements. The strip specimens were hung by means of platinum hooks, suspended from aluminum oxide rods in the furnace; the disc specimens were supported by the edges only on ceramic forms resting on a rigid ceramic slab. All of the specimens were then enclosed in a ceramic muffle. Starting with ambient conditions, the temperature of the furnace was raised to 1523°K (1250°C) over a period of six hours, and held at that temperature for one hour. The power was then turned off, and the specimens were allowed to cool in the furnace, which required two days.

The specimens were removed from the furnace by means of cleaned, platinym tipped tongs and were placed in individual plastic holders, in which they were supported by the ends or edges only. Each plastic holder, containing a specimen, was then placed in an individual cardboard box, to protect the specimen from contamination.

The two 1/4 x 8-inch strips were prepared for measurement by welding a platinum-platinum 10% rhodium thermocouple to each specimen. A shallow groove was scratched in each specimen, normal to its axis and located at the midlength. The 10-mil thermocouple wires were separately welded to the specimen by means of a condenser-discharge type of electronic spot welder. Each wire was laid in the shallow groove to position it for welding, and the welding operation was observed through a low-power microscope.

Three sets of curves were made for each strip specimen at each of three temperatures, 800°, 1100° and 1300°K. Each set of curves consisted of (1) a 100% curve, obtained when the two blackbody furnaces at the test temperature served as sources for the respective beams, (2) a zero curve, obtained with the specimen beam blocked near the specimen furnace, and (3) a specimen curve, obtained with the comparison blackbody at the test temperature as source for the comparison beam, and the hot specimen at the same temperature serving as source for the specimen beam. The height of each curve was recorded on punched paper tape at each 0.1 revolution of the wavelength dial over the range corresponding to approximately 1 to 15 microns.

The punched paper tape containing the raw emittance data was fed into an IBM 7090 computer, which then corrected the recorded emittance of the specimen at each wavelength on the basis of the recorded 100% and zero curves.

The corrected emittance values for the six measurements, three each on two specimens, were then fed back into the computer, and the following values were computed at each of the approximately 110 wavelengths. (1), E, the average emittance, (2) σ_m, the standard deviation[1/] due to error of measurement, computed as the average standard deviation of the three measurements on each specimen about the mean for that specimen, and (3) σ_s, the standard deviation due to differences in specimens.

1/ All standard deviations in this study are precisely defined as "estimates of the standard deviation of the parent population from which the measurements were drawn." Mathematically

$$\sigma_m = \sqrt{\frac{\sum_1^n(x-\bar{x}_1)^2+\sum_1^n(x-\bar{x}_2)^2..+\sum_1^n(x-\bar{x}_p)}{(n-1)p}}$$

where x is an individual measurement, $\bar{x}$, is the average of n measurements on specimen one, and p is the number of specimens. (For data in this report, n = 3 in all cases, and p = 2 for platinum-13% alloy and 6 for oxidized sandblasted Inconel.)

$$\sigma_s = \sqrt{\frac{\sum_1^p(\bar{x}_1-\bar{\bar{x}})^2}{p-1}}$$

where x is the overall average of the n x p measurements, n each on p specimens.

The values obtained on the platinum-13% rhodium specimens are tabulated in Table I, and are shown in figures 1 through 6.

The spectral emittance curves for the platinum-13% rhodium alloy, shown in figure 1 at 800°K, figure 2 at 1100°K and figure 3 at 1300°K, are quite similar to the corresponding curves for platinum.

The principal differences are that (1) in general, the emittance of the platinum-13% rhodium alloy is higher than that of platinum at the same temperature and at the same wavelength, (2) the maximum at about 1.4 micron at 800°K is lower for the platinum-13% rhodium alloy than for platinum, (3) the maximum at about 1.36 micron for platinum and 1100°K has moved to about 1.12 microns for platinum-13% rhodium and (4) no evidence of a maximum at 15 microns or beyond is seen in the platinum-13% rhodium data.

The standard deviations σ_s and σ_m are plotted as a function of wavelength in figure 4 at 800°K, figure 5 at 1100°K and figure 6 at 1300°K. In general the σ_m values show less variation with wavelength than the σ_s values. The average values of σ_m were 0.23 at 800°K, 0.19 at 1100°K and 0.33 at 1300°K, and the corresponding values of σ_s were 0.25 at 800°K, 0.57 at 1100°K and 0.91 at 1300°K. However, the σ_s values are based on only two specimens, and hence are not highly reliable.

The increase in precision (lower σ_m values)over what was obtained in the tests on platinum reported in WADC TR 59-510 Pt IV can be ascribed in part to the reduction in error due to direct recording of data by the data-processing attachment as compared to reading the curves with a variable scale.

Oxidized Inconel Working Standards

Specimens were cut from 2 x 8 inch Inconel sheet. Six strips, 1/4 x 8 inches in size were cut from the two edges of the sheet, three from each edge. Twelve discs, 0.484-inch in diameter, were cut from the center of the sheet. All specimens were marked for identification, and the position and orientation of each specimen in the original sheet was recorded. The specimens were sandblasted with 60-mesh fused alumina grit and an air pressure of approximately 70 psi, care being taken to obtain a uniformly rough surface on all specimens. The sandblasted specimens were cleaned ultrasonically in acetone, passivated for one minute in 10% nitric acid at 316°K (43°C), rinsed in distilled water and then in freshly distilled acetone. The cleaned specimens were subjected to a minimum of handling. When handling was unavoidable, rubber surgical gloves were worn, and the specimens were touched only by the ends or edges.

The strip specimens were suspended from a metal rack by means of oxidation-resistant metal hooks, and the rack was inserted into a cold furnace. The disc specimens were supported by the edges only on special ceramic supports placed on the hearth of the furnace, and enclosed in a ceramic muffle. The furnace was brought to 1340°K (1067°C) and held for 24 hours, then dropped to 1100°K (827°C) and held for an additional 24 hours, after which the specimens were allowed to cool in the furnace.

The specimens were removed from the furnace by means of cleaned stainless steel tongs, and were placed in individual plastic holders, in which they were supported by the ends or edges only. Each plastic holder, containing a specimen, was then placed in an individual cardboard box, to protect the specimen against contamination.

The six 1/4 x 8 inch strips were prepared for measurement by welding a platinum-platinum 10% rhodium thermocouple to each specimen. The oxide coating was removed in narrow strips and a shallow groove was scratched in each specimen near its mid length and normal to its axis. The oxide was also removed by grinding for a distance of approximately one inch from each end. The thermocouples were welded by a procedure similar to that used for the platinum-13% rhodium specimens.

The normal spectral emittance of each of the six specimens was measured three times at each of three temperatures, and the data were analyzed statistically, as in the case of the platinum-13% rhodium specimens. The results are shown in Table II and are plotted as a function of wavelength in figures 7 through 12.

The general shape of the spectral emittance curves is similar to that obtained on the previous standards, but the emittance at each wavelength is somewhat higher. There was a slight increase in emittance with an increase in temperature at each wavelength.

The values of σ_m[2/] and σ_s[2/] obtained at 800^{o}K are plotted in figure 10, at 1100^{o}K in figure 11 and at 1300^{o}K in figure 12.

In general the values of σ_s were somewhat larger than those of σ_m, and showed greater variation with wavelength. The average values of σ_m were 0.70 at 800^{o}K, 0.59 at 1100^{o}K and 0.63 at 1300^{o}K and the corresponding values of σ_s were 0.82 at 800^{o}K, 1.04 at 1100^{o}K and 1.00 at 1300^{o}K. This is a considerable improvement in reproducibility of specimens over what was obtained in the tests reported in WADC TR 59-510 Pt IV, and is part due to the fact that the specimens were cut from adjacent portions of the original sheet.

There is also some improvement in precision over the corresponding data reported in WADC TR 59-510 Pt IV, which can again be ascribed to a reduction in the reading error due to use of the data-processing attachment.

2/ See footnote 1 on page 3.

V. EQUATIONS RELATING SPECTRAL EMISSIVITY OF METALS TO OTHER PROPERTIES

In this phase of the work, a study is being directed toward explaining the irregularities and inflections observed in experimental emissivity (reflectivity) data. The mechanism of this phenomenon is thought to be characterized by contribution of several types of free and bound electrons. As stated in the previous report, no set of parameters has yet been determined for the metal rhodium that will produce a normal spectral reflectivity curve which fits the observed data over a wide wavelength interval (0.1 to 10μ), both generally and in detail.

The computer program used in the process of determining the best values of the parameters is being modified to calculate the optical constants. These values will be compared with experimental data available from the literature. This comparison should give an indication of the physical creditability of this approach.

To date a small fraction of the total effort in this project has been devoted to this phase of the work. In the following quarter, efforts will be intensified to determine whether this approach merits a continued or enhanced use in achieving a better understanding of the principles governing spectral variation in the emissivity of metals.

TABLE I

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
1.18	24.2	.16	.19
1.25	25.5	.49	.26
1.33	26.1	.29	.94
1.40	26.2	.30	.90
1.48	25.2	.15	1.06
1.58	23.7	.23	.97
1.68	22.1	.30	.78
1.81	20.6	.18	.73
1.98	19.2	.24	.64
2.23	17.7	.36	.42
2.51	16.5	.34	.33
2.73	15.4	.29	.26
2.92	14.7	.29	.07
3.14	13.8	.38	.05
3.35	13.2	.27	.07
3.56	12.6	.20	.14
3.77	12.2	.20	.26
3.98	11.7	.16	.19
4.20	11.3	.15	.38
4.41	11.0	.33	.14
4.58	10.8	.26	.19
4.76	10.5	.27	.19
4.91	10.2	.23	.31
5.07	10.1	.23	.35
5.21	9.9	.20	.21
5.34	9.7	.27	.31
5.47	9.7	.17	.42
5.60	9.5	.22	.40
5.76	9.3	.22	.40
5.90	9.1	.09	.45
6.04	8.9	.15	.40
6.16	8.7	.20	.35
6.28	8.7	.15	.28
6.41	8.6	.16	.31
6.53	8.6	.21	.24

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
6.64	8.5	.33	.31
6.76	8.4	.22	.33
6.87	8.4	.16	.38
6.97	8.4	.21	.42
7.07	8.4	.20	.28
7.19	8.3	.21	.40
7.32	8.2	.18	.47
7.44	8.2	.15	.40
7.56	8.1	.19	.45
7.66	8.0	.12	.49
7.77	8.0	.20	.33
7.88	7.9	.21	.35
7.98	7.9	.15	.35
8.08	7.9	.23	.33
8.18	7.8	.23	.26
8.28	7.8	.24	.28
8.38	7.9	.24	.33
8.47	8.0	.31	.12
8.57	8.0	.22	.19
8.66	8.0	.23	.26
8.75	8.1	.22	.14
8.84	8.1	.26	.16
8.93	8.1	.17	.24
9.01	8.0	.13	.12
9.10	8.0	.18	.19
9.18	8.1	.23	.33
9.26	8.1	.24	.16
9.35	8.6	.25	.02
9.43	9.1	.25	.02
9.51	9.4	.13	.05
9.67	9.3	.16	.26
9.83	8.6	.31	.21
10.00	8.1	.14	.19
10.15	7.8	.24	.19
10.30	7.6	.24	.19

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
10.46	7.3	.23	.07
10.61	7.2	.31	.14
10.76	7.1	.15	.09
10.91	7.0	.34	.14
11.05	7.0	.29	.16
11.19	6.9	.23	.24
11.32	6.8	.25	.16
11.45	6.8	.18	.05
11.58	6.6	.30	.16
11.72	6.6	.14	.14
11.84	6.5	.19	.09
11.97	6.6	.24	.26
12.09	6.4	.39	.21
12.22	6.5	.20	.12
12.35	6.4	.22	.12
12.48	6.4	.24	.12
12.60	6.2	.18	.12
12.72	6.2	.16	.09
12.85	6.2	.20	.16
12.98	6.2	.17	.19
13.10	6.2	.18	.09
13.22	6.2	.23	.05
13.34	6.0	.30	.09
13.46	6.0	.23	.05
13.58	6.0	.19	.09
13.69	5.9	.23	.09
13.81	5.9	.28	.12
13.93	5.8	.17	.07
14.03	5.8	.32	.26
14.14	5.8	.30	.24
14.25	5.7	.26	.21
14.36	5.7	.27	.19
14.47	5.7	.22	.14
14.58	5.6	.41	.09
14.68	5.5	.31	.09

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
14.79	5.6	.27	.02
14.90	5.6	.33	.07
15.01	5.7	.22	.02
15.11	5.6	.26	.07

1/ Average of 6 measured values, three each on two specimens.

2/ See footnote 1 on page 3 in the text.

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
1.07	23.1	.45	.14
1.12	23.3	.47	.24
1.18	23.1	.48	.02
1.25	22.5	.56	.14
1.33	22.3	.50	.24
1.40	21.8	.39	.09
1.48	21.3	.37	.02
1.58	20.7	.37	
1.68	20.0	.34	.02
1.81	19.1	.29	.07
1.98	18.5	.26	.16
2.23	17.7	.29	.21
2.51	16.8	.24	.16
2.73	16.1	.17	.14
2.92	15.7	.22	.38
3.14	15.0	.27	.54
3.35	14.6	.34	.61
3.56	14.2	.38	.61
3.77	13.9	.34	.94
3.98	13.5	.35	1.11
4.20	13.1	.23	1.06
4.41	12.7	.16	1.15
4.58	12.5	.16	1.11
4.76	12.2	.21	1.13
4.91	12.0	.21	1.13
5.07	11.8	.10	1.13
5.21	11.6	.14	1.23
5.34	11.4	.20	1.15
5.47	11.2	.18	1.18
5.60	11.0	.24	1.30
5.76	10.9	.13	1.15
5.90	10.7	.12	1.06
6.04	10.5	.18	.97
6.16	10.5	.13	.94
6.28	10.4	.13	.94

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1100°K

Wavelength / Microns	Emittance[1/] / X100	σ_m[2/] / X100	σ_s[2/] / X100
6.41	10.3	.18	.99
6.53	10.1	.12	.75
6.64	10.0	.17	.80
6.76	9.8	.18	.78
6.87	9.8	.08	.94
6.97	9.6	.14	.94
7.07	9.6	.13	1.08
7.19	9.5	.22	1.04
7.32	9.5	.17	.99
7.44	9.4	.18	1.01
7.56	9.4	.20	1.01
7.66	9.3	.15	.97
7.77	9.2	.15	.94
7.88	9.2	.09	.92
7.98	9.1	.13	.94
8.08	9.0	.19	.90
8.18	9.1	.19	.90
8.28	9.1	.15	.80
8.38	9.0	.09	.82
8.47	9.1	.08	.90
8.57	9.2	.12	.78
8.66	9.2	.11	.87
8.75	9.3	.08	.75
8.84	9.2	.15	.73
8.93	9.2	.06	.73
9.01	9.3	.11	.68
9.10	9.3	.08	.61
9.18	9.2	.12	.64
9.26	9.2	.16	.66
9.35	9.3	.15	.68
9.43	9.7	.11	.73
9.51	10.0	.18	.52
9.67	10.2	.07	.42
9.83	9.8	.12	.31
10.00	9.4	.19	.31

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.15	9.0	.31	.35
10.30	8.6	.20	.28
10.46	8.4	.24	.54
10.61	8.4	.20	.52
10.76	8.2	.10	.42
10.91	8.1	.19	.40
11.05	8.0	.19	.38
11.19	7.8	.14	.38
11.32	7.8	.15	.54
11.45	7.7	.11	.61
11.58	7.6	.14	.54
11.72	7.5	.21	.45
11.84	7.4	.16	.33
11.97	7.4	.15	.47
12.09	7.3	.06	.40
12.22	7.3	.08	.38
12.35	7.2	.15	.42
12.48	7.2	.10	.49
12.60	7.2	.08	.38
12.72	7.1	.08	.26
12.85	7.0	.17	.26
12.98	7.0	.11	.24
13.10	6.9	.11	.38
13.22	6.9	.04	.16
13.34	6.9	.17	.21
13.46	6.9	.13	.19
13.58	6.8	.08	.05
13.69	6.8	.09	.14
13.81	6.7	.13	.16
13.93	6.8	.11	.26
14.03	6.6	.22	.19
14.14	6.6	.14	.21
14.25	6.5	.22	.05
14.36	6.5	.20	.31
14.47	6.4	.19	.19

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
14.58	6.5	.16	.12
14.68	6.5	.22	.28
14.79	6.5	.17	.19
14.90	6.4	.14	.19
15.01	6.4	.25	.21
15.11	6.4	.37	.31

1/ Average of 6 measured values, three each on two specimens.

2/ See footnote 1 on page 3 in the text.

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
1.07	25.4	1.07	.28
1.12	25.2	.94	.14
1.18	24.7	.87	.02
1.25	24.3	.68	.12
1.33	23.7	.43	
1.40	23.1	.40	.02
1.48	22.6	.30	.02
1.58	22.0	.29	.19
1.68	21.2	.24	.28
1.81	20.4	.43	.19
1.98	19.7	.29	.38
2.23	18.7	.39	.40
2.51	18.0	.41	.57
2.73	17.3	.32	.57
2.92	16.6	.23	.59
3.14	16.2	.21	.75
3.35	15.9	.16	.97
3.56	15.3	.15	.87
3.77	15.0	.23	1.06
3.98	14.6	.26	1.11
4.20	14.4	.25	1.18
4.41	14.0	.23	1.30
4.58	13.8	.26	1.53
4.76	13.7	.31	1.65
4.91	13.3	.23	1.72
5.07	13.2	.26	1.81
5.21	12.9	.27	1.77
5.34	12.8	.18	1.74
5.47	12.7	.18	1.74
5.60	12.5	.19	1.65
5.76	12.3	.25	1.70
5.90	12.1	.21	1.60
6.04	11.9	.25	1.63
6.16	11.6	.29	1.60
6.28	11.6	.31	1.65

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
6.41	11.6	.36	1.86
6.53	11.3	.38	1.67
6.64	11.2	.29	1.63
6.76	11.1	.38	1.65
6.87	11.0	.27	1.65
6.97	10.9	.22	1.65
7.07	10.8	.20	1.56
7.19	10.8	.15	1.46
7.32	10.7	.13	1.60
7.44	10.7	.22	1.56
7.56	10.6	.18	1.58
7.66	10.4	.28	1.63
7.77	10.4	.24	1.53
7.88	10.4	.13	1.53
7.98	10.4	.25	1.63
8.08	10.4	.27	1.60
8.18	10.3	.29	1.44
8.28	10.3	.19	1.39
8.38	10.2	.19	1.48
8.47	10.2	.20	1.46
8.57	10.2	.15	1.34
8.66	10.2	.17	1.37
8.75	10.2	.17	1.41
8.84	10.3	.19	1.32
8.93	10.2	.17	1.34
9.01	10.3	.18	1.34
9.10	10.2	.22	1.23
9.18	10.2	.15	1.18
9.26	10.2	.15	1.18
9.35	10.2	.16	1.30
9.43	10.2	.13	1.25
9.51	10.5	.10	1.20
9.67	10.9	.12	1.06
9.83	11.0	.10	.99
10.00	10.5	.12	1.06

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance [1] X100	σ_m [2] X100	σ_s [2] X100
10.15	10.0	.27	1.04
10.30	9.7	.20	.92
10.46	9.5	.33	1.04
10.61	9.2	.15	.97
10.76	9.1	.15	.97
10.91	9.0	.08	.75
11.05	8.9	.12	.78
11.19	8.8	.16	.85
11.32	8.7	.25	.80
11.45	8.5	.09	.85
11.58	8.5	.09	.73
11.72	8.4	.17	.71
11.84	8.3	.14	.66
11.97	8.2	.19	.59
12.09	8.0	.20	.68
12.22	8.1	.09	.57
12.35	8.0	.15	.57
12.48	7.9	.13	.47
12.60	7.8	.20	.45
12.72	7.8	.16	.21
12.85	7.7	.15	.24
12.98	7.6	.14	.28
13.10	7.5	.11	.19
13.22	7.5	.17	.26
13.34	7.5	.28	.33
13.46	7.4	.19	.05
13.58	7.3	.17	.21
13.69	7.2	.12	.16
13.81	7.3	.15	.02
13.93	7.3	.15	.16
14.03	7.2	.18	.16
14.14	7.2	.16	.02
14.25	7.2	.13	.05
14.36	7.1	.11	.02
14.47	7.2	.16	

TABLE I cont'd.

NORMAL SPECTRAL EMITTANCE OF
PLATINUM RHODIUM WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance [1/] X100	σ_m [2/] X100	σ_s [2/] X100
14.58	7.0	.16	.09
14.68	7.2	.21	.07
14.79	7.1	.16	.05
14.90	7.0	.23	.07
15.01	7.2	.19	
15.11	7.2	.18	.05

1/ Average of 6 measured values, three each on two specimens.

2/ See footnote 1 on page 3 in the text.

TABLE II

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.18	82.0	.77	1.84
1.25	83.5	.88	1.19
1.33	84.5	.97	1.53
1.40	85.1	.70	1.67
1.48	85.1	.82	1.59
1.58	84.7	.85	1.50
1.68	84.2	.58	1.60
1.81	83.9	.66	1.55
1.98	83.5	1.07	1.66
2.23	84.5	.81	1.22
2.51	83.3	.81	.98
2.73	83.2	.85	.88
2.92	82.8	.83	.88
3.14	82.7	.66	.78
3.35	82.6	.56	.73
3.56	82.5	.56	.75
3.77	82.4	.63	.76
3.98	82.1	.70	.89
4.20	82.1	.58	.93
4.41	82.1	.66	.76
4.58	82.1	.68	.65
4.76	81.9	.50	.61
4.91	81.7	.67	.64
5.07	81.6	.80	.39
5.21	81.7	.77	.45
5.34	81.6	.93	.52
5.47	81.6	.85	.52
5.60	81.5	.87	.55
5.76	81.3	.72	.64
5.90	81.3	.66	.67
6.04	81.3	.81	.58
6.16	81.1	.65	.58
6.28	81.1	.83	.48
6.41	81.1	.66	.55
6.53	81.1	.63	.57

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance [1/] X100	σ_m [2/] X100	σ_s [2/] X100
6.64	81.1	.65	.49
6.76	81.3	.63	.47
6.87	81.5	.62	.47
6.97	81.8	.76	.55
7.07	82.1	.70	.49
7.19	82.8	1.40	.80
7.32	82.8	.55	.59
7.44	83.1	.73	.60
7.56	83.3	.66	.61
7.66	83.6	.64	.56
7.77	83.9	.67	.60
7.88	84.2	.66	.61
7.98	85.0	.62	.66
8.08	85.9	.67	.60
8.18	86.5	.67	.62
8.28	87.1	.62	.64
8.38	87.5	.57	.65
8.47	87.5	.70	.75
8.57	87.7	.66	.80
8.66	87.9	.70	.84
8.75	88.1	.81	.95
8.84	88.2	.67	.88
8.93	88.4	.61	.92
9.01	88.4	1.60	1.15
9.10	88.9	1.04	.83
9.18	89.1	.73	.80
9.26	89.3	.78	.83
9.35	89.4	.72	.82
9.43	89.2	.68	.73
9.51	88.8	.73	.76
9.67	88.4	.68	.82
9.83	88.3	.67	.80
10.00	88.3	.68	.72
10.15	88.6	.60	.75
10.30	88.9	.50	.82

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.46	89.4	.56	.84
10.61	89.5	.78	.98
10.76	89.7	.74	.93
10.91	90.0	.57	.74
11.05	90.2	.73	.71
11.19	90.5	.57	.81
11.32	90.6	.64	.81
11.45	90.7	.79	.87
11.58	90.8	.67	.85
11.72	91.1	.67	.75
11.84	91.3	.65	.67
11.97	91.5	.57	.78
12.09	91.6	.68	.81
12.22	91.8	.77	.76
12.35	92.0	.70	.77
12.48	92.4	.64	.80
12.60	92.9	.60	.89
12.72	93.0	.65	.95
12.85	93.3	.68	.89
12.98	93.4	.55	.80
13.10	93.8	.52	.83
13.22	94.1	.53	.79
13.34	94.2	.59	.81
13.46	94.3	.59	.90
13.58	94.4	.59	.84
13.69	94.3	.61	.86
13.81	94.0	.61	.80
13.93	93.3	.53	.85
14.03	91.7	.59	.85
14.14	89.8	.67	.82
14.25	87.6	.69	.86
14.36	85.2	.79	.91
14.47	82.8	.79	.92
14.58	80.5	.74	.92
14.68	78.2	.70	.87

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 800°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
14.79	75.9	.72	.91
14.90	73.9	.61	.84
15.01	72.3	.79	.89
15.11	70.8	.57	.89

1/ Average of 18 measured values, three each on six specimens.

2/ See footnote 1 on page 3 in the text.

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m[2/] X100	σ_s[2/] X100
1.07	89.4	1.10	3.13
1.12	89.5	.80	3.28
1.18	89.4	.76	3.17
1.25	89.3	.59	3.17
1.33	89.1	.57	2.87
1.40	88.9	.55	2.75
1.48	88.6	.66	2.51
1.58	88.1	.70	2.31
1.68	87.7	.77	2.05
1.81	87.4	.59	1.69
1.98	86.9	.50	1.61
2.23	86.7	.52	1.43
2.51	86.3	.55	1.53
2.73	85.7	.59	1.44
2.92	85.5	.60	1.48
3.14	85.4	.52	1.41
3.35	85.2	.53	1.36
3.56	85.0	.53	1.36
3.77	84.9	.58	1.25
3.98	84.8	.59	1.19
4.20	84.6	.66	1.11
4.41	84.5	.52	.92
4.58	84.4	.55	1.01
4.76	84.4	.60	.97
4.91	84.2	.81	1.32
5.07	84.3	.60	1.22
5.21	84.4	.63	1.17
5.34	84.5	.56	1.10
5.47	84.6	.53	1.11
5.60	84.5	.54	.97
5.76	84.0	1.21	1.45
5.90	83.9	.97	1.12
6.04	84.0	.78	.97
6.16	83.8	.69	.87
6.28	83.9	.54	.90

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
6.41	84.0	.61	.93
6.53	83.9	.51	.95
6.64	84.0	.51	.99
6.76	84.2	.57	.99
6.87	84.6	.64	1.03
6.97	84.8	.52	.95
7.07	85.0	.55	.91
7.19	85.2	.53	.87
7.32	85.3	.47	.80
7.44	85.4	.46	.70
7.56	85.6	.44	.67
7.66	85.7	.50	.60
7.77	86.0	.50	.69
7.88	86.2	.57	.67
7.98	86.7	.51	.77
8.08	87.1	.49	.74
8.18	87.6	.51	.56
8.28	88.0	.62	.54
8.38	88.4	.49	.59
8.47	88.6	.53	.56
8.57	88.7	.62	.48
8.66	88.9	.50	.51
8.75	88.9	.57	.45
8.84	89.0	.64	.51
8.93	89.3	.46	.50
9.01	89.4	.42	.60
9.10	89.5	.43	.65
9.18	89.7	.38	.73
9.26	89.8	.44	.74
9.35	89.9	.47	.72
9.43	90.0	.49	.62
9.51	90.0	.62	.47
9.67	89.8	.58	.27
9.83	89.9	.50	.33
10.00	89.9	.53	.44

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.15	90.0	.39	.48
10.30	90.1	.39	.49
10.46	90.2	.47	.45
10.61	90.4	.54	.48
10.76	90.7	.46	.65
10.91	90.9	.38	.71
11.05	91.2	.43	.60
11.19	91.4	.42	.45
11.32	91.6	.47	.33
11.45	91.6	.54	.37
11.58	91.9	.50	.42
11.72	92.1	.37	.53
11.84	92.2	.33	.53
11.97	92.3	.58	.47
12.09	92.5	.57	.41
12.22	92.7	.59	.45
12.35	93.0	.59	.43
12.48	93.2	.52	.53
12.60	93.5	.44	.65
12.72	93.7	.48	.62
12.85	93.8	.53	.57
12.98	94.0	.61	.55
13.10	94.4	.56	.52
13.22	94.9	.62	.71
13.34	95.1	.51	.77
13.46	95.3	.51	.70
13.58	95.4	.63	.64
13.69	95.4	.71	.67
13.81	95.4	.59	.62
13.93	95.4	.46	.71
14.03	95.3	.38	.94
14.14	94.8	.37	1.11
14.25	93.8	.42	1.16
14.36	92.4	.66	1.44
14.47	90.9	.70	1.52

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1100°K

Wavelength / Microns	Emittance 1/ / X100	σ_m 2/ / X100	σ_s 2/ / X100
14.58	89.1	.58	1.57
14.68	87.3	.53	1.65
14.79	85.4	.48	1.80
14.90	83.3	.49	1.89
15.01	81.3	.63	2.04
15.11	80.3	4.68	3.36

1/ Average of 18 measured values, three each on six specimens.

2/ See footnote 1 on page 3 in the text.

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1] X100	σ_m[2] X100	σ_s[2] X100
1.07	91.7	1.57	2.87
1.12	91.4	1.59	2.68
1.18	91.2	1.45	2.52
1.25	91.0	1.63	2.37
1.33	90.8	1.53	2.10
1.40	90.4	1.22	1.90
1.48	89.8	1.26	1.71
1.58	89.4	1.13	1.57
1.68	88.8	.96	1.57
1.81	88.3	.88	1.45
1.98	87.9	.72	1.46
2.23	87.4	.93	1.38
2.51	86.9	1.15	1.53
2.73	86.5	.83	1.21
2.92	86.3	.83	1.15
3.14	86.1	.84	1.01
3.35	86.0	.72	.94
3.56	86.0	.71	.96
3.77	86.0	.63	.94
3.98	86.0	.66	.79
4.20	85.8	.42	.84
4.41	85.7	.67	.91
4.58	85.7	.73	.85
4.76	85.6	.54	.74
4.91	85.6	.54	.74
5.07	85.6	.49	.71
5.21	85.6	.61	.77
5.34	85.6	.61	.79
5.47	85.6	.63	.83
5.60	85.6	.65	.79
5.76	85.5	.75	.86
5.90	85.4	.49	.80
6.04	85.5	.53	.79
6.16	85.5	.56	.81
6.28	85.6	.31	.81

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
6.41	85.7	.38	.80
6.53	85.7	.63	.71
6.64	85.7	.51	.68
6.76	85.8	.56	.69
6.87	86.0	.52	.77
6.97	86.1	.60	.69
7.07	86.1	.59	.75
7.19	86.3	.70	.69
7.32	86.5	.71	.68
7.44	86.7	.65	.88
7.56	86.9	.58	.87
7.66	87.0	.61	.95
7.77	87.3	.45	.97
7.88	87.5	.42	.88
7.98	87.7	.37	.85
8.08	88.0	.40	.79
8.18	88.2	.54	.67
8.28	88.4	.42	.65
8.38	88.8	.36	.62
8.47	89.4	1.05	.66
8.57	89.4	.64	.55
8.66	89.5	.64	.55
8.75	89.6	.59	.61
8.84	89.7	.56	.66
8.93	89.8	.56	.67
9.01	90.0	.49	.82
9.10	90.1	.58	.76
9.18	89.9	.98	.98
9.26	90.2	.68	.76
9.35	90.3	.51	.77
9.43	90.3	.57	.80
9.51	90.4	.69	.79
9.67	90.6	.99	.72
9.83	90.4	.89	.71
10.00	90.3	.83	.72

TABLE II cont'd

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance[1/] X100	σ_m [2/] X100	σ_s [2/] X100
10.15	90.4	.72	.79
10.30	90.5	1.38	.93
10.46	90.8	.79	.79
10.61	90.9	1.36	.95
10.76	91.0	.54	.82
10.91	91.2	.55	.61
11.05	91.4	.59	.81
11.19	91.7	.50	.84
11.32	92.0	.54	.78
11.45	92.1	.58	.71
11.58	92.2	.47	.66
11.72	92.3	.58	.83
11.84	92.6	.53	.80
11.97	92.9	.51	.72
12.09	93.0	.56	.72
12.22	93.2	.52	.62
12.35	93.3	.54	.69
12.48	93.6	.51	.76
12.60	93.9	.45	.70
12.72	94.3	.38	.72
12.85	94.4	.48	.72
12.98	94.7	.74	.59
13.10	94.9	.60	.57
13.22	95.1	.52	.64
13.34	95.5	.67	.68
13.46	95.6	.40	.67
13.58	95.8	.50	.59
13.69	95.8	.57	.64
13.81	96.0	.85	.56
13.93	96.0	.50	.63
14.03	95.8	.46	.62
14.14	95.5	.53	.75
14.25	94.9	.62	.88
14.36	94.0	1.13	1.06
14.47	93.1	.79	1.40

TABLE II cont'd.

NORMAL SPECTRAL EMITTANCE OF
OXIDIZED INCONEL WORKING STANDARDS AT 1300°K

Wavelength Microns	Emittance 1/ X100	σ_m 2/ X100	σ_s 2/ X100
14.58	91.9	1.09	2.00
14.68	90.1	1.01	2.09
14.79	88.4	1.04	2.28
14.90	86.4	.99	2.51
15.01	84.5	1.07	2.57
15.11	82.7	1.05	2.73

1/ Average of 18 measured values, three each on six specimens.

2/ See footnote 1 on page 3 in the text.

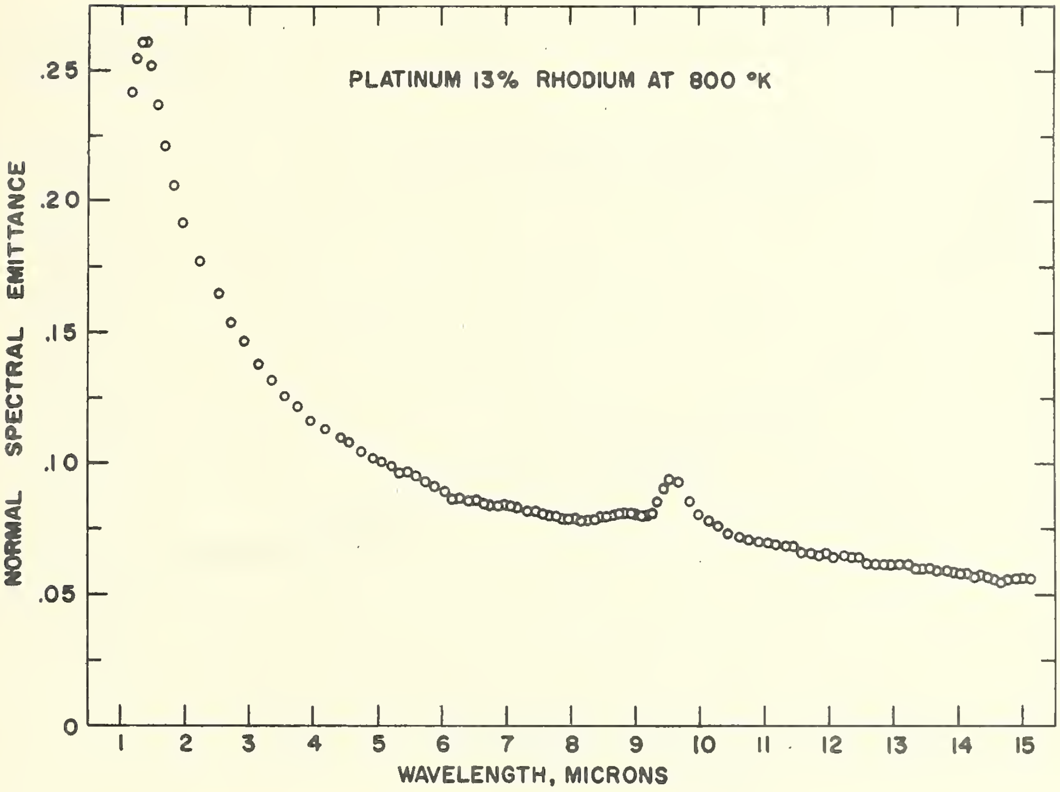

Fig. 1. Normal spectral emittance of 0.484-inch disc working standards of platinum-13% rhodium alloy at 800 °K. The plotted values are averages of six measured values, three each on two specimens.

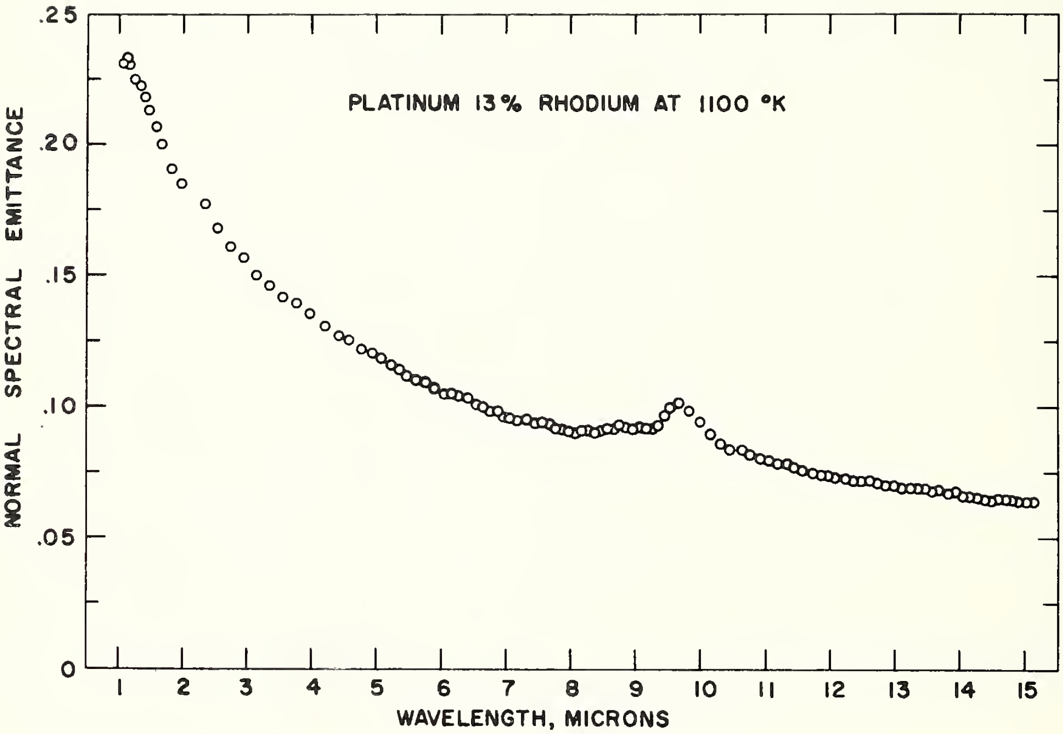

Fig. 2. Normal spectral emittance of 0.484-inch disc working standards of platinum-13% rhodium alloy at 1100°K. The plotted values are averages of six measured values, three each on two specimens.

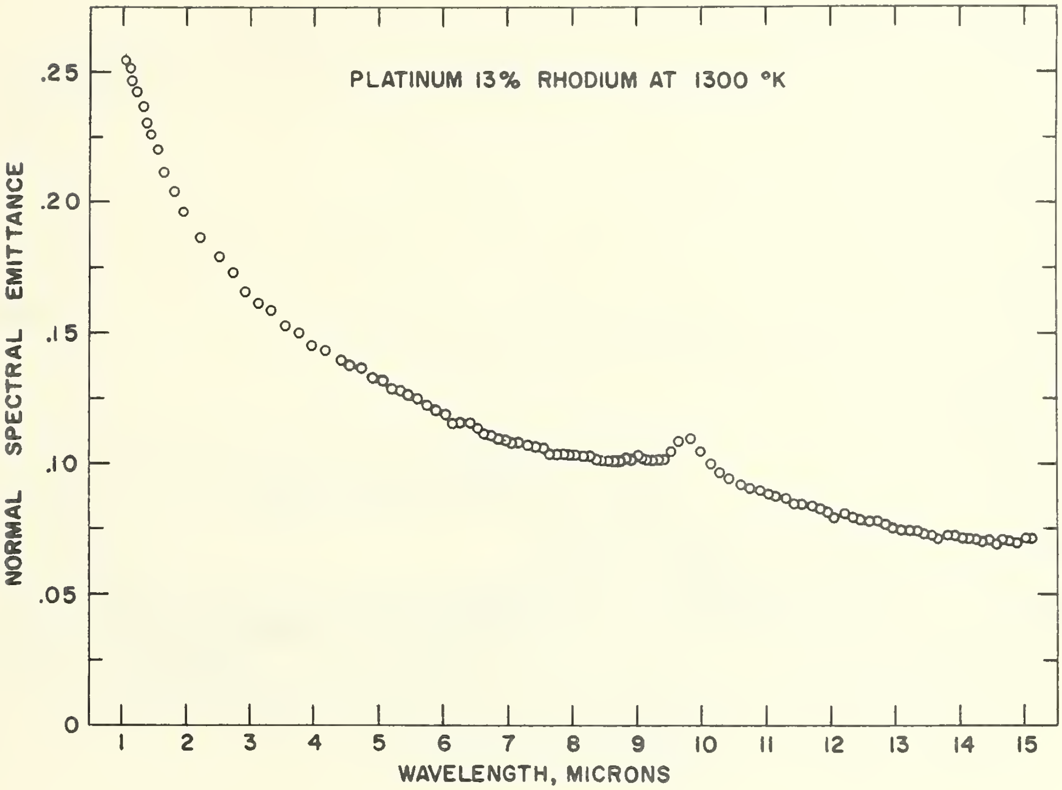

Fig. 3. Normal spectral emittance of 0.484-inch disc working standards of platinum-13% rhodium alloy at 1300 °K. The plotted values are averages of six measured values, three each on two specimens.

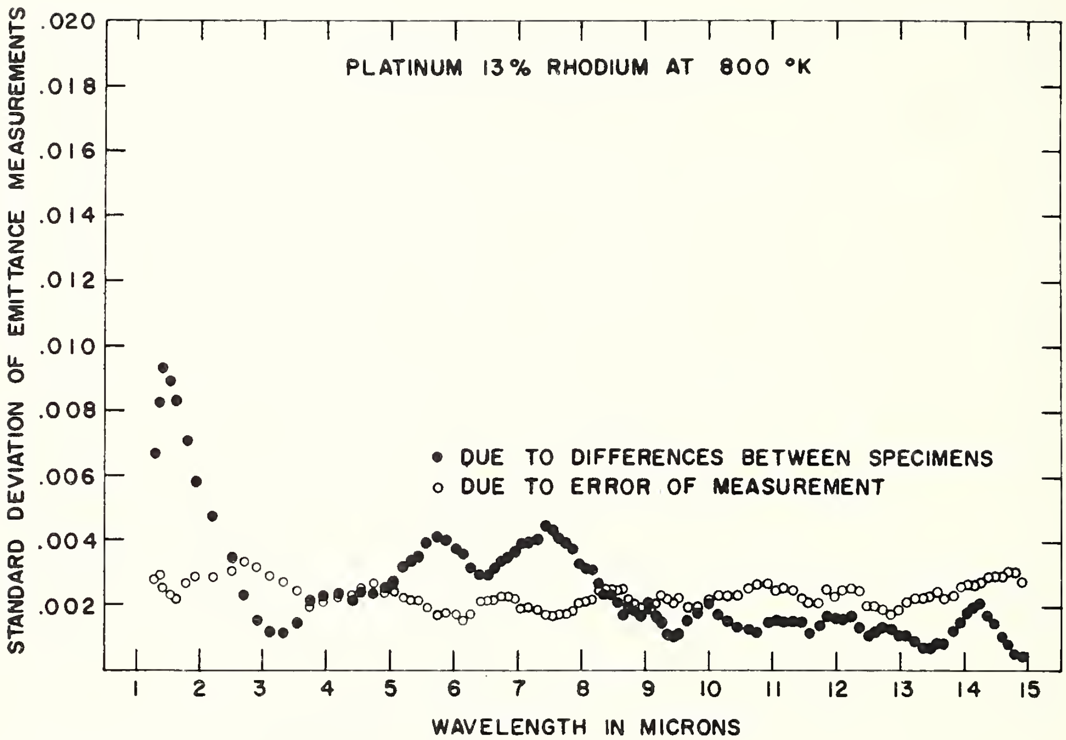

Fig. 4. Spectral distribution of two categories of standard deviations, each computed from six measured emittance values obtained at 800°K, three each on two specimens of platinum-13% rhodium alloy. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

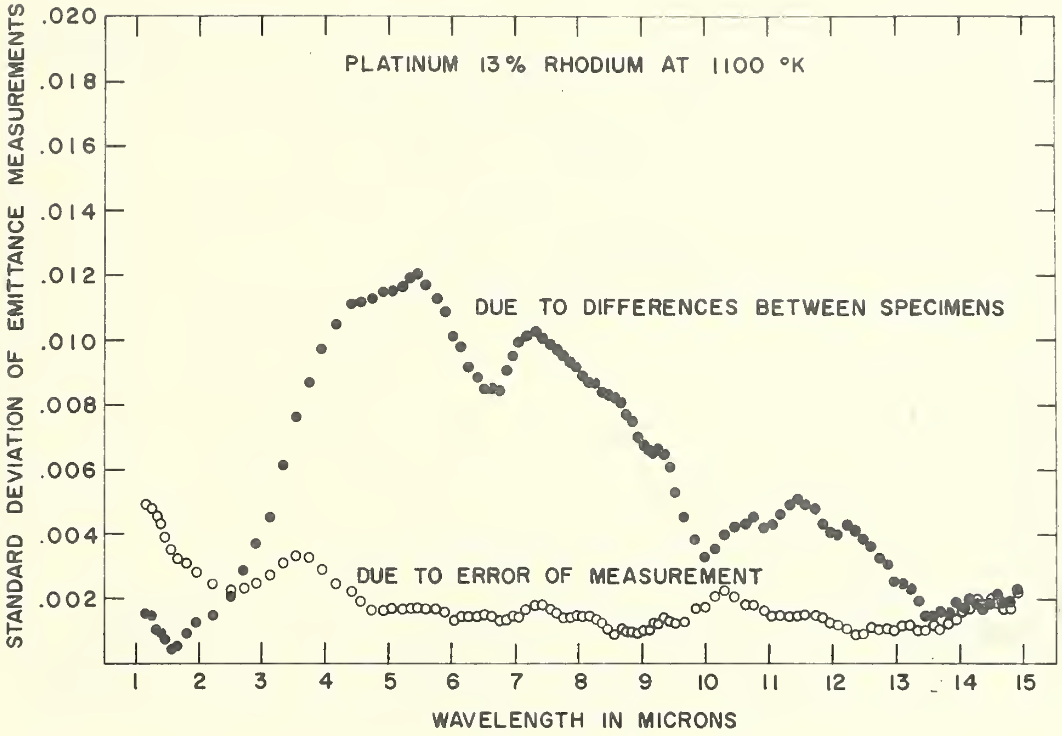

Fig. 5. Spectral distribution of two categories of standard deviations, each computed from six measured emittance values obtained at 1100 ^{o}K, three each on two specimens of platinum-13% rhodium alloy. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

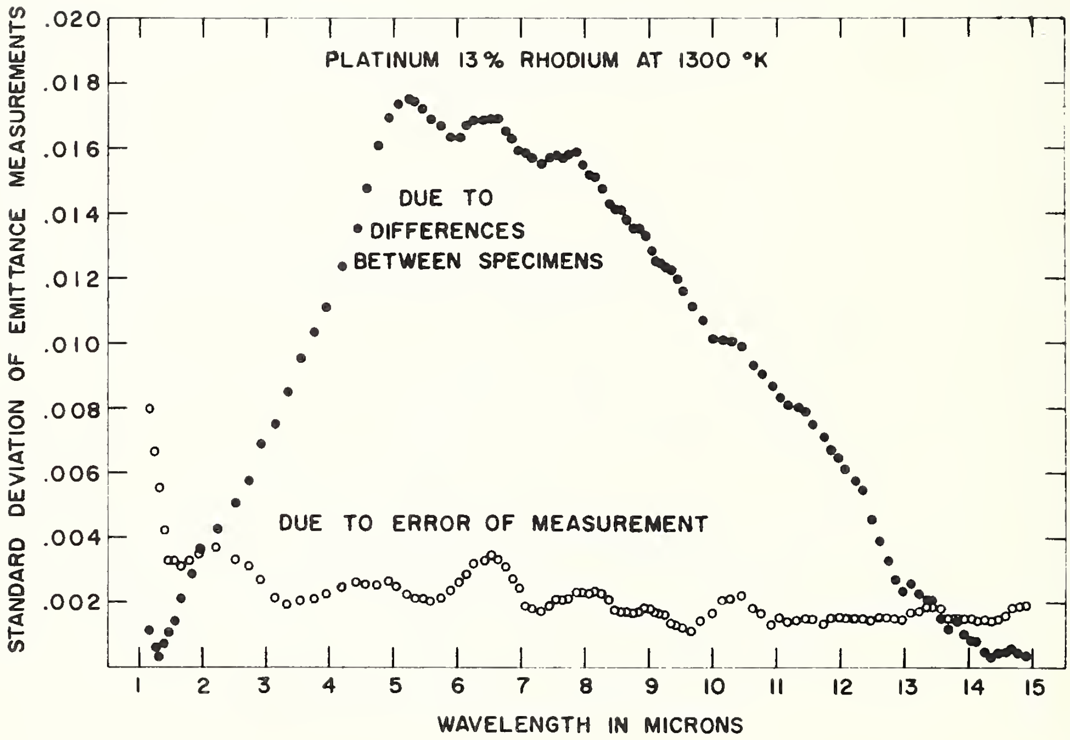

Fig. 6. Spectral distribution of two categories of standard deviations, each computed from six measured emittance values obtained at 1300°K, three each on two specimens of platinum-13% rhodium alloy. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

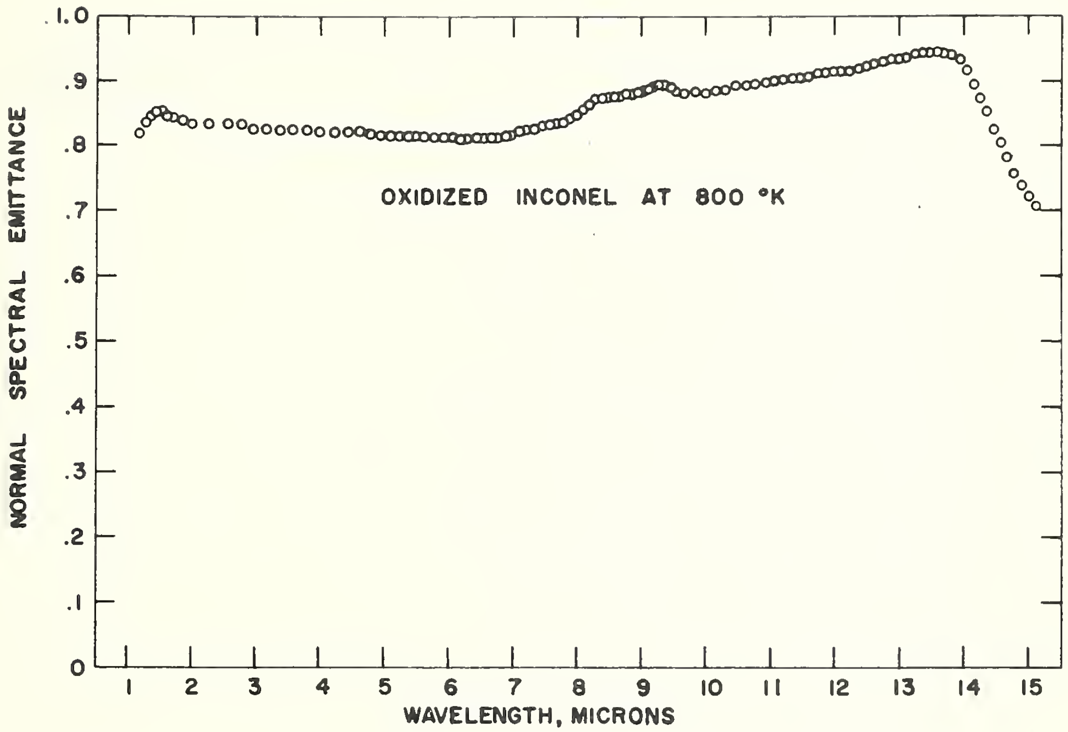

Fig. 7. Normal spectral emittance of 0.484-inch disc working standards of oxidized sandblasted Inconel at 800°K. The plotted values are averages of 18 measured values, three each on six specimens.

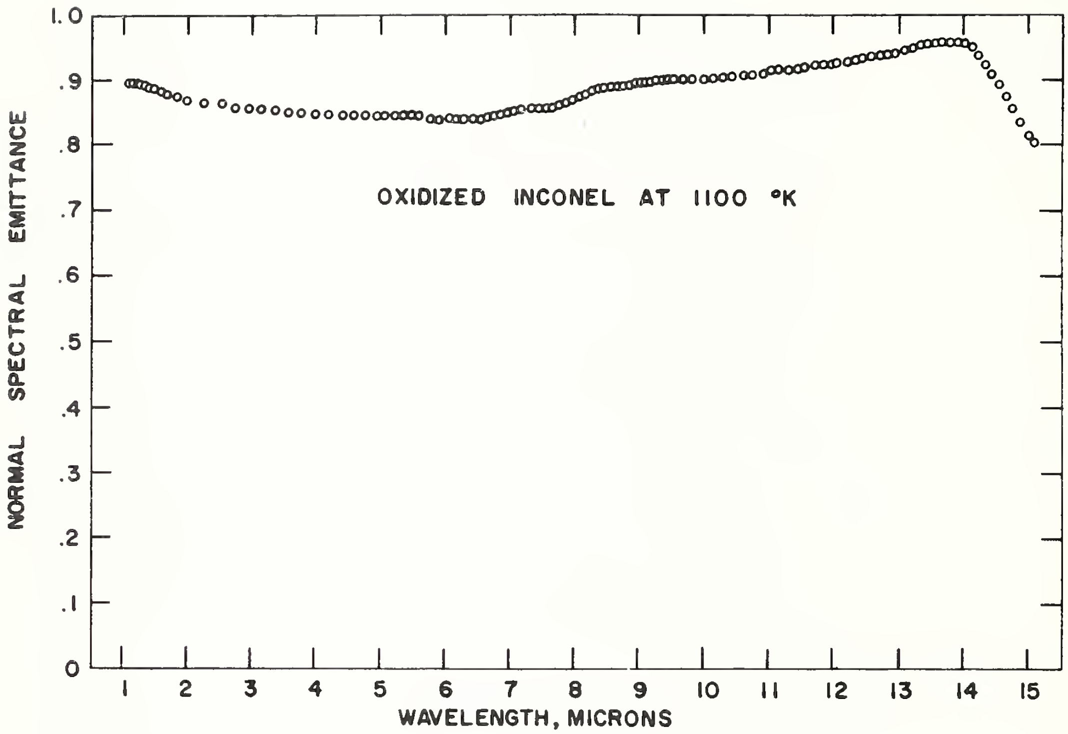

Fig. 8. Normal spectral emittance of 0.484-inch disc working standards of oxidized sandblasted Inconel at 1100°K. The plotted values are averages of 18 measured values, three each on six specimens.

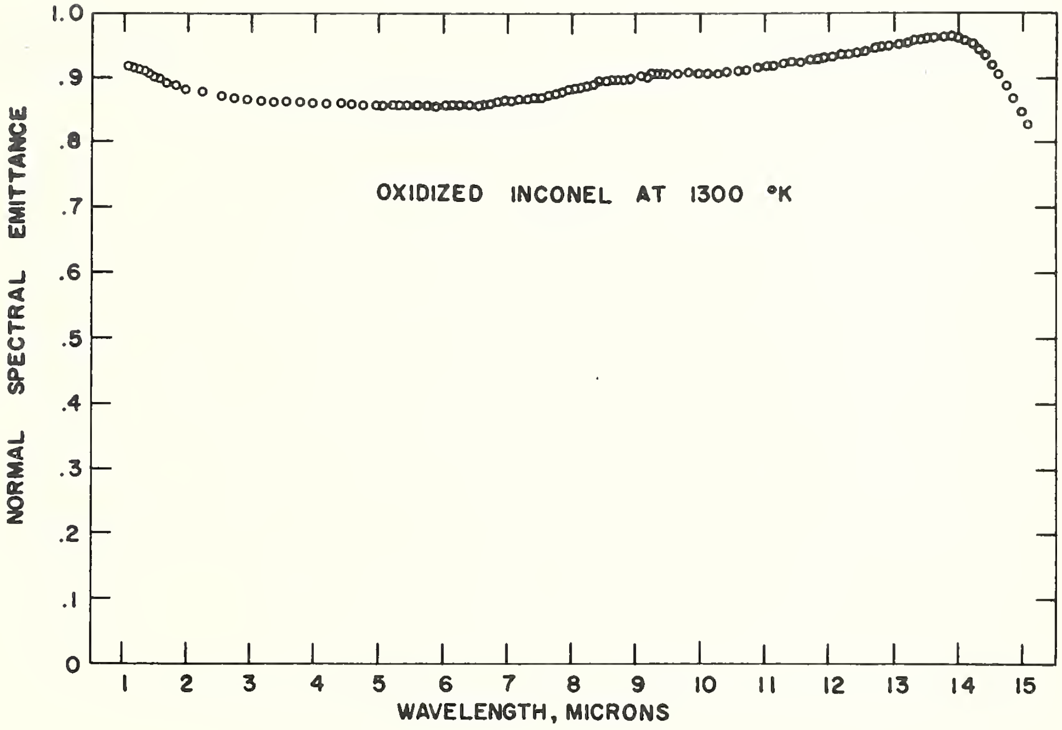

Fig. 9. Normal spectral emittance of 0.484 inch-disc working standards of oxidized sandblasted Inconel at 1300 °K The plotted values are averages of 18 measured values, three each on six specimens.

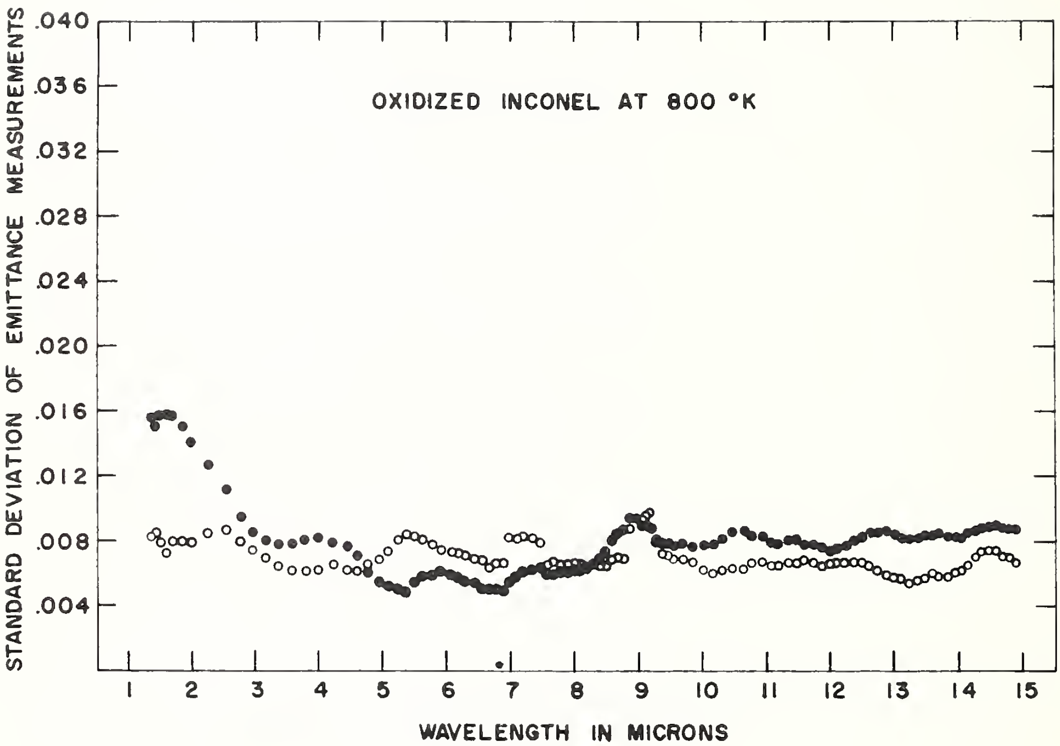

Fig. 10. Spectral distribution of two categories of standard deviations, each computed from 18 measured emittance values obtained at 800°K, three each on six specimens of oxidized sandblasted Inconel. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

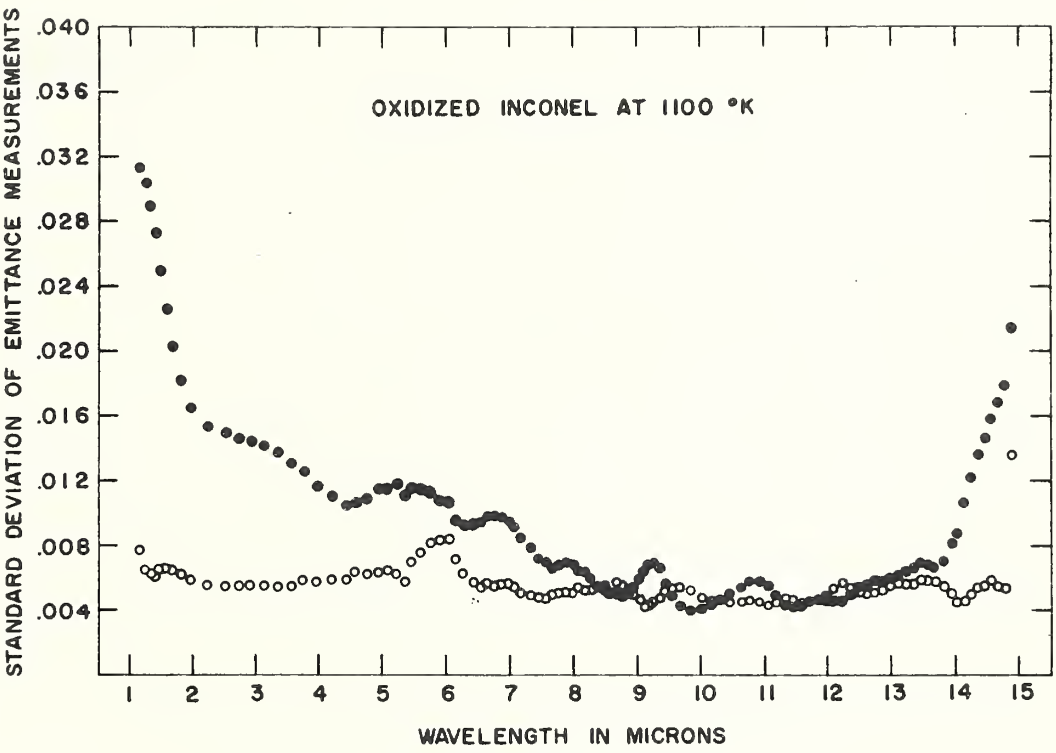

Fig. 11. Spectral distribution of two categories of standard deviations, each computed from 18 measured emittance values obtained at 1100°K, three each on six specimens of oxidized sandblasted Inconel. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

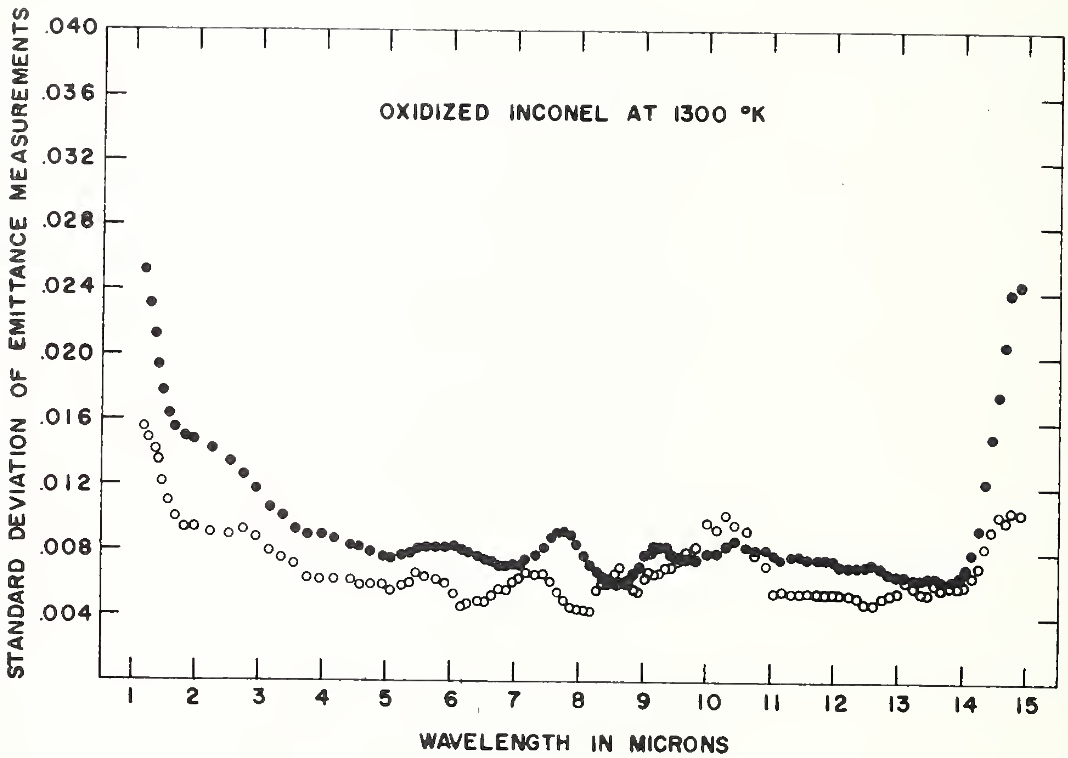

Fig. 12. Spectral distribution of two categories of standard deviations, each computed from 18 measured emittance values obtained at 1300°K, three each on six specimens of oxidized sandblasted Inconel. The upper curve represents standard deviations due to differences in emittance between specimens, identified as σ_s in the text. The lower curve represents standard deviations due to random error, identified as σ_m in the text. In both curves, each point represents the moving average of five adjacent values.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

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Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

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